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Street Illumination of Champaign

Electrical Engineering

B. S.

1911

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STREET ILLUMINATION OF CHAMPAIGN

BY

EDWARD MYRON JASPER
ELMER FRANKLIN HEATER

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
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May 29 1911

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Edward Myron Jasper and Elmer Franklin Heater

ENTITLED Street Illumination of Champaign

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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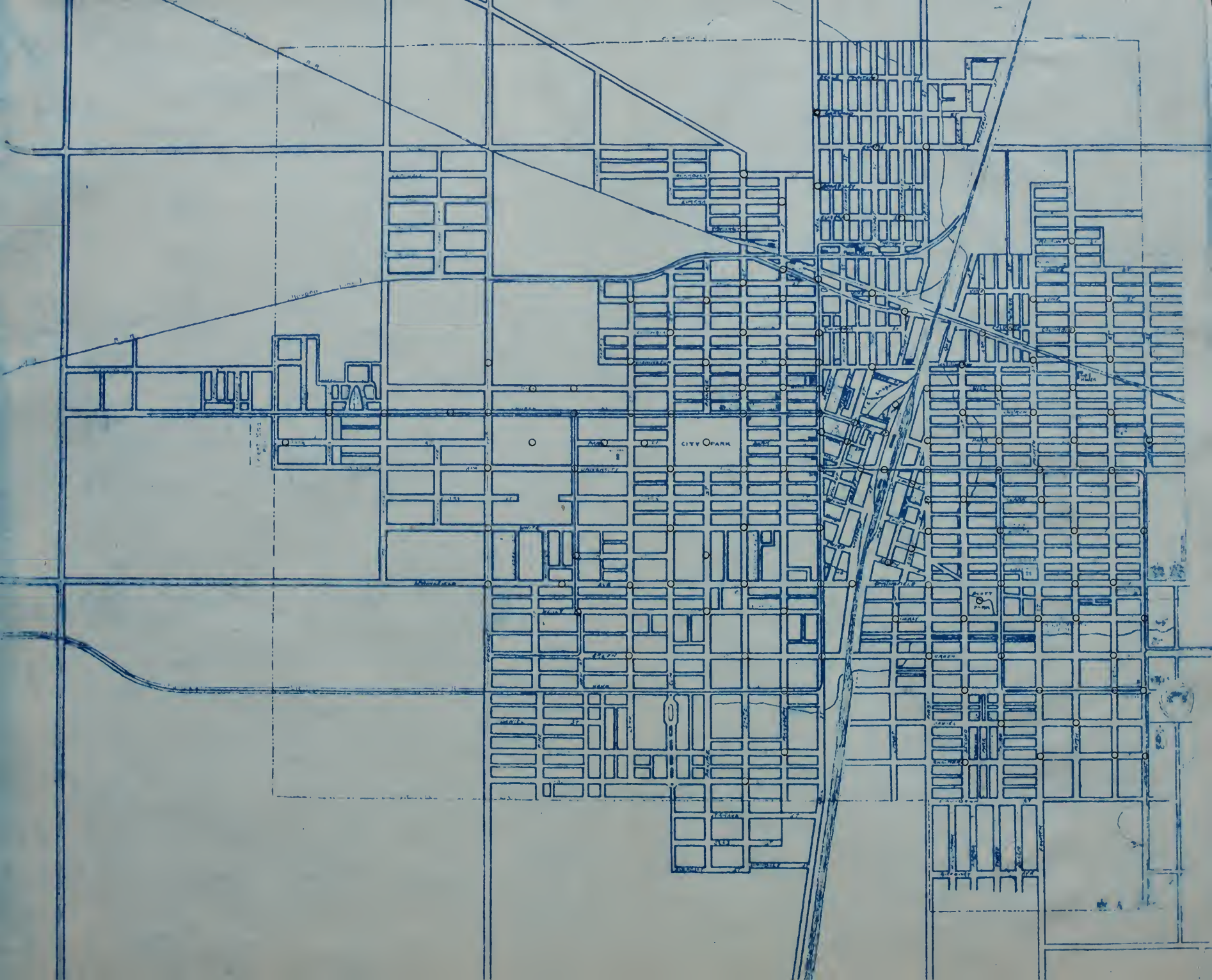

CITY PARK

INTRODUCTION

There are two methods of measuring light, one depending upon the physical energy of radiation, the other depending upon the sensation produced upon the eye. For all practical purposes it has been found most desirable to use the latter method. The reasons for this are that it is difficult to measure the energy due to luminous radiation and that the effect of the different wave lengths is readily detected by the eye.

This explains why there is no rigid system of units as found in other branches of science and engineering. The basis of the system as it now exists, was originally derived from the light giving power of some standard source of light. The system was developed in the various countries independently and after about a century of evolution the definition and relation of the various units of luminous intensity was fixed in 1909. It would seem that the English and American systems were favored, as the new unit, called the International Candle, was made equal to the English and American candle. The German unit, the Hefner, was given as equal to .90 of the International Candle and the French unit, the Carcel, was considered equal to 9.615 International Candles. The Hefner and Carcel are lamp units obtained from special lamps burning under certain specified conditions. The English and American

units were derived originally from the luminous intensity of the candle flame, whence the term candle-power. From this fundamental unit the remaining units and terms are derived.

If a light source has an average intensity in all directions of one candle-power, the light from that source is equal to one mean spherical candle-power, or simply one mean spherical candle. The density of the light flux falling upon a surface is termed the illumination of that surface. The unit of illumination,as commonly used in this country, is the foot-candle and denotes the illumination at a surface, every point of which is one foot from a light source whose luminous intensity is one candle-power. A term closely connected with the term illumination, and which is of great importance in lighting is luminosity. From the definition given above, illumination is the measure of the light flux which falls upon or strikes a surface. Luminosity is a measure of the density of the light flux given out or diffused by a surface. The relation between the two terms is that the luminosity of a surface reflecting or diffusing light is equal to the illumination received by the surface multiplied by a constant called its coefficient of absorption. This principle has a decided bearing upon the use of frosted or opaque globes surrounding light sources and also upon indirect illumination.

The original standard used was the candle. The disadvantage of the candle as a source was its variability, the action being quite dependent upon atmospheric conditions. The German and French standards were substituted for it finally, and

they have proved very satisfactory. They are easily duplicated in construction and their action is not so variable as is that of the old standard.

The standards are, however, frequently unnecessary in some of the problems of exterior illumination. As a substitute, so called comparison standards are used, the chief of which is the incandescent lamp. It has been found that after a preliminary burning of about 100 hours the lamp maintains practically a constant intensity for a period of use of from 75 to 100 hours. This furnishes the principal requisite of a standard, namely, that it possess constancy of calibration. The lamp is calibrated by finding simultaneously the values of current and voltage at which the desired illumination is secured.

PRINCIPLES AND INSTRUMENTS

Since the investigation and study of an arc lighting system is the primary object of this paper, it will not be digressing too widely to take up a brief discussion of the principles and instruments involved in such an investigation. It will be seen at once that to obtain any data on the performance of the lamps, a portable photometer must be used. The construction of an instrument that should give satisfactory results and yet be convenient both in use and transportation was treated as a secondary object.

The first instrument with which experiments were conducted was of a type which is manufactured by the General Electric Company, and is shown in Figure 1. It consists of a box of blackened interior fitted with two tubes. Through one of these tubes the light enters and falls upon a card placed in the rear of the box directly in front of the other tube. The card bears characters in type of different de-

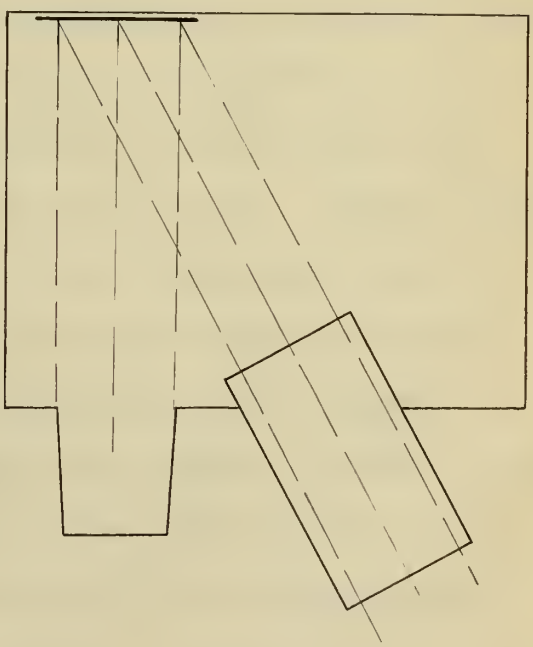


Figure 1.

grees of boldness. By looking through the sight tube the distance from the illuminant at which one of the sets of characters becomes indistinguishable is found. Having by previous calibration determined the value of the intensity of illumination at which each set of characters becomes indistinguishable, the candle-power of any light source may be found in a way which will be described in a subsequent paragraph.

In this instrument, as it is at present manufactured, the light and observation tubes are made of wood and when not in use are removed and placed inside the box for convenience in carrying. Obviously this is rather a clumsy arrangement and renders the instrument somewhat inconvenient of operation.

In order to eliminate these disadvantages an instrument of the same type, but smaller in size and having collapsible tubes, was designed. The tubes were to be attached permanently to the front of the box, but as already suggested, so constructed that they could be folded within the box when not in use. These changes would add greatly to the compactness of the luminometer and render it much easier to operate. From tests made with the model, however, it was found that this instrument would be somewhat more inaccurate than was desired, and this together with the difficulties which would be encountered in the construction of the finished product would render it unsuited to the investigation which is the primary object of this paper.

A further attempt to obtain a suitable instrument resulted in the construction of a luminometer such as the one shown in Figure 2. It consists of a box with blackened interior, having

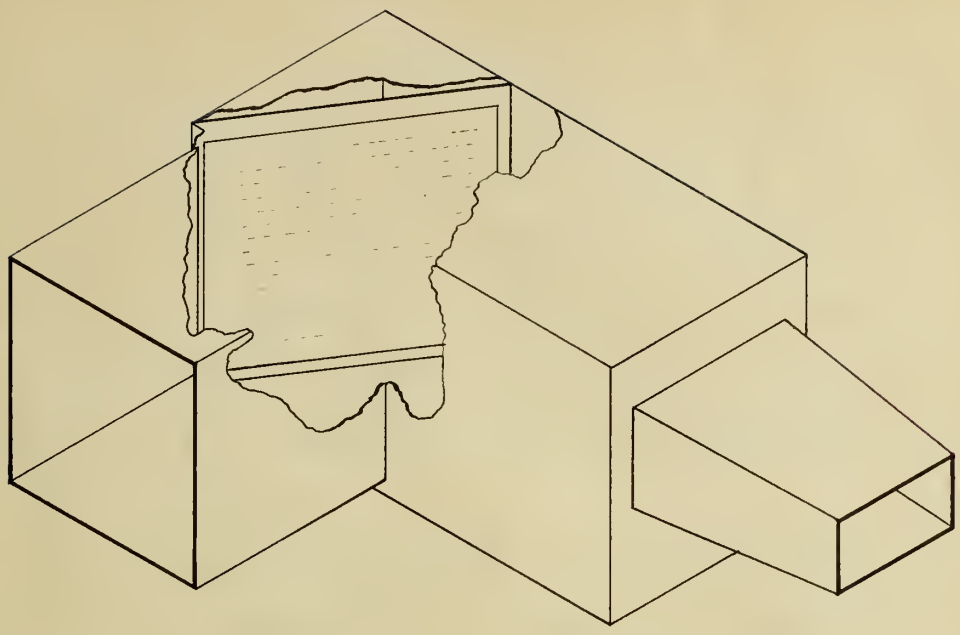


Figure 2 - 45° Instrument

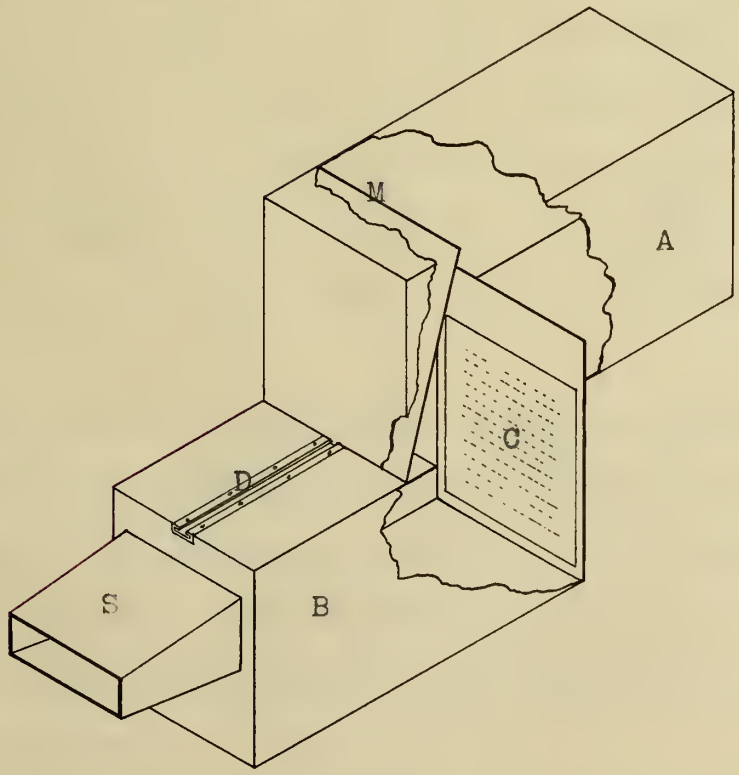


Figure 3 - Mirror Instrument

at one end a sight tube and on one side, at right angles to the line of sight, a light tube. Directly in front of the light tube, and at 45° to the line of sight, is placed a card bearing various characters in type. The method of using this instrument and the principles upon which it is based are the same as were mentioned in connection with the luminometer first described and will be found in a later paragraph.

This 45° instrument, as it is called, is very simple in construction, but in operation it is very unsatisfactory because of the reflection from the surface of the card. With the card in the 45° position this reflection was so great as to render the printed characters almost indistinguishable at any distance from the light source, and even when the card was placed at an angle greater than 45° with the line of sight, the reflection was found to be very annoying to the eye and of sufficient intensity to render the sensibility of the instrument practically nil. These disadvantages prevented the use of this particular instrument in obtaining the data for the curves and calculations which appear later.

After several unsatisfactory tests had been made with the above mentioned instruments, a luminometer was designed which possesses many of the desirable features of the others and at the same time is free from most of their disadvantages. It has, in addition, advantages peculiar to itself which are due, chiefly, to its construction.

An outline diagram of this instrument is shown in Fig-

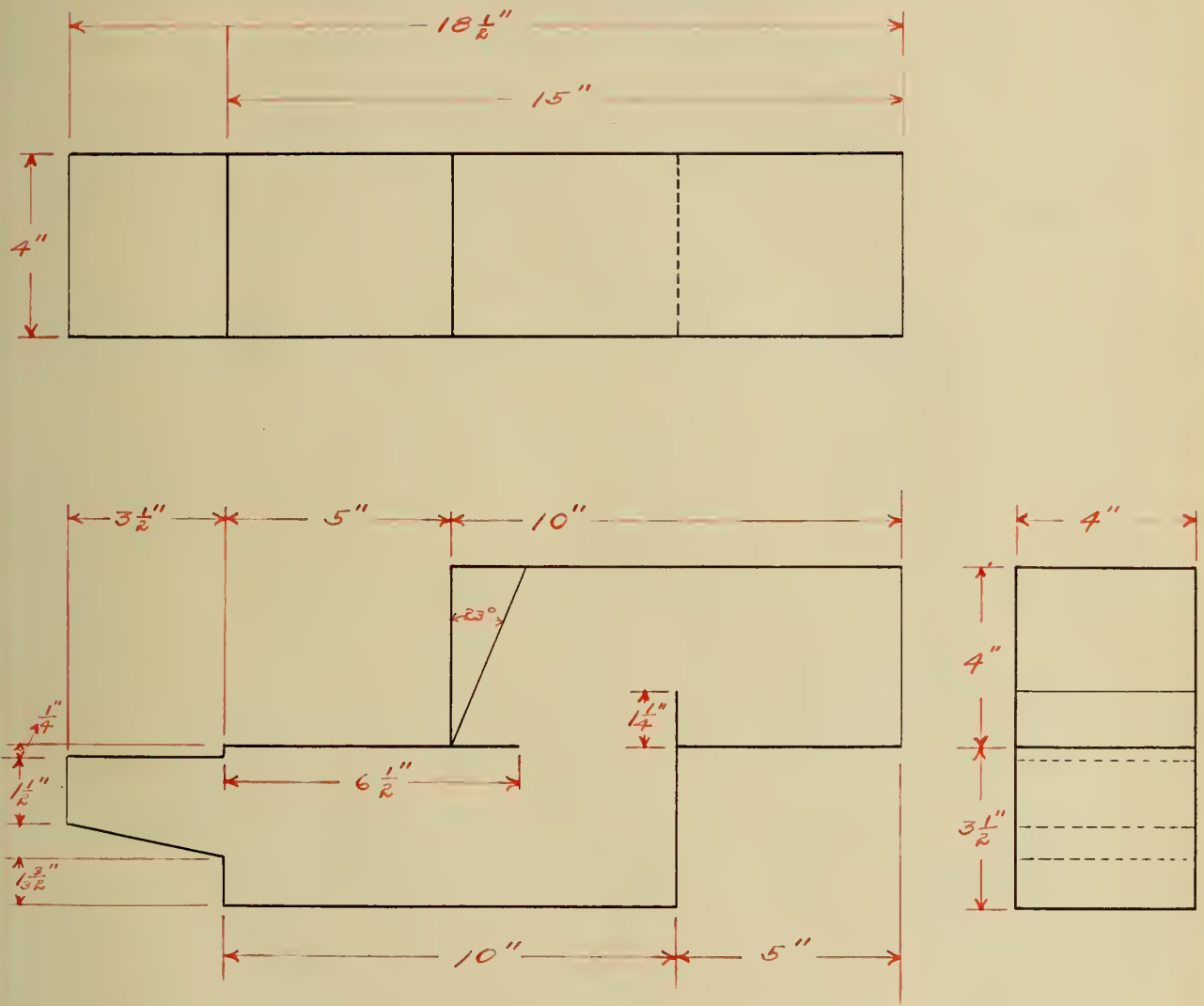


Figure 4.

ure 3. It consists essentially of two boxes, A and B, each with blackened interior, a sight tube S and a mirror M. Box A is mounted above B and connected to it by the brass guides D. The diagram shows the instrument extended and ready for use. When not in use A is moved back until it is directly over B, the sight tube is made to slide into B by means of guides, and the openings of S and A closed by small doors or shutters. At C, and with its plane perpendicular to the line of vision, is placed a card bearing different characters in type. The mirror is placed at such an angle with the plane of the card that the light reflected by the mirror is distributed evenly over the entire card. This angle is, of course, dependent upon the dimensions of the instrument, and in the present case was found to be 23°.

One very commendable feature of this instrument is the effectiveness with which it excludes all light except that from the source upon which observations are being made, unless, of course, there is also another source in the line of sight. If the second source is in any position other than in the line of sight, very few, if any rays from it can reach the surface of the card.

This is due to three things, the length and the absorbing action of the blackened interior of the light tube, and the fact that the angle of reflection from the mirror is equal to the angle of incidence of the ray with the surface of the mirror. Since the angle which the mirror makes with the plane of the card is determined by considering the incident rays perpendicular to the plane of the card, it is seen that with a source of light be-

low the line of vision the greater part of the light reflected by the mirror would fall above the card, and with a source above the line of vision the reflected light would fall below the card.

The principle upon which this instrument is based is the fundamental principle of photometry, namely, that the intensity of illumination at any point varies directly as the luminous intensity of the source and inversely as the square of the distance from the point to the source. If then the intensity of illumination be found at a given distance from a known standard source of light, the luminous intensity of any other source may be determined by finding the distance from that source at which the intensity is the same as was that from the standard. Denoting by C. P. the luminous intensity of the source in candle-power, and by I the intensity in foot-candles of the illumination at any point distant D feet from the source, the relation existing between C. P., I and D is given by the equation $I = \frac{C.\ P.}{D^2}$ or $C.\ P. = I\ D^2$. This equation, being perfectly general, furnishes a means of determining the candle-power of any light source by the method of comparison with a source of known luminous intensity. In this comparison it is assumed that certain characters on the screeen are rendered equally distinguishable by illumination of the same intensity from any one of a number of light sources. Thus, if these characters can be distinguished with illumination of an intensity calculated from the candle-power of a standard placed at a given distance from the screen, then knowing the distance from any other source to the point at which the characters

are as readily distinguishable as before, the solution is reversed resulting in an expression for the candle power of the source.

There are three general methods of photometry which might be used in this investigation and these in their order of accuracy are: the flicker photometer method, the comparison photometer method, and the method of visual acuity.

The chief objections to the first two are that they require instruments with complicated arrangement of parts. In the flicker type of instrument for instance, the rotating device for the screen would be very inconvenient, making the instrument impracticable for outdoor investigations. The size of case required for the proper mounting of the screens and comparison lamp in the comparison type of instrument render it also unsuitable for any class of work where portability is desired. The method employing visual acuity overcomes these objections quite effectively, although the method is not as accurate as the others.

There seems to be much disagreement, however, as to the degree of accuracy of this method. One writer states that it is merely a rough and ready means of comparison, while another holds that differences of illumination of twenty or thirty per cent can not be detected with it. He also maintains that the method is fitted not for light measurements, but only for detecting different orders of illumination. Notwithstanding these disparaging statements a model of the instrument,as previously described, was constructed and data taken with it subsequently, would tend to indicate that the above statements are somewhat overdrawn for data

agreeing to within ten per cent and less were obtained consistently. There are, moreover, authorities who defend this method and in view of these conflicting opinions it is difficult to state with finality the exact degree of accuracy obtainable with this method. Much depends upon the characteristics of the particular eye using the instrument, and upon the methods followed in obtaining data and in using the latter in the calculations.

Returning to the old definition that efficiency equals the ratio of output to input, the visual efficiency may be denoted by the ratio of the output of the eye in performing its duty to the input of nervous energy to secure this output. This visual efficiency, as it is called, is dependent for best results upon two very important factors. The first of these is the sensitiveness of the eye, or its ability to detect differences in luminosity. The second is the acuity of the eye or, as it is commonly termed, visual acuity. The acuity of the eye is its ability to distinguish fine detail.

The curves shown in Figure 5, on the next page, and taken from Wickenden's "Illumination and Photometry", show the variation of sensitiveness and acuity with various luminosities, the curves being taken on white light illumination. It is seen that for values of luminosity from zero to one foot candle the sensitiveness of the eye to changes in luminosity has a very rapid decrease. After one foot candle is reached the sensitiveness becomes practically constant. On the other hand, the acuity increases until slightly more than one foot candle is reached when it too becomes almost constant.

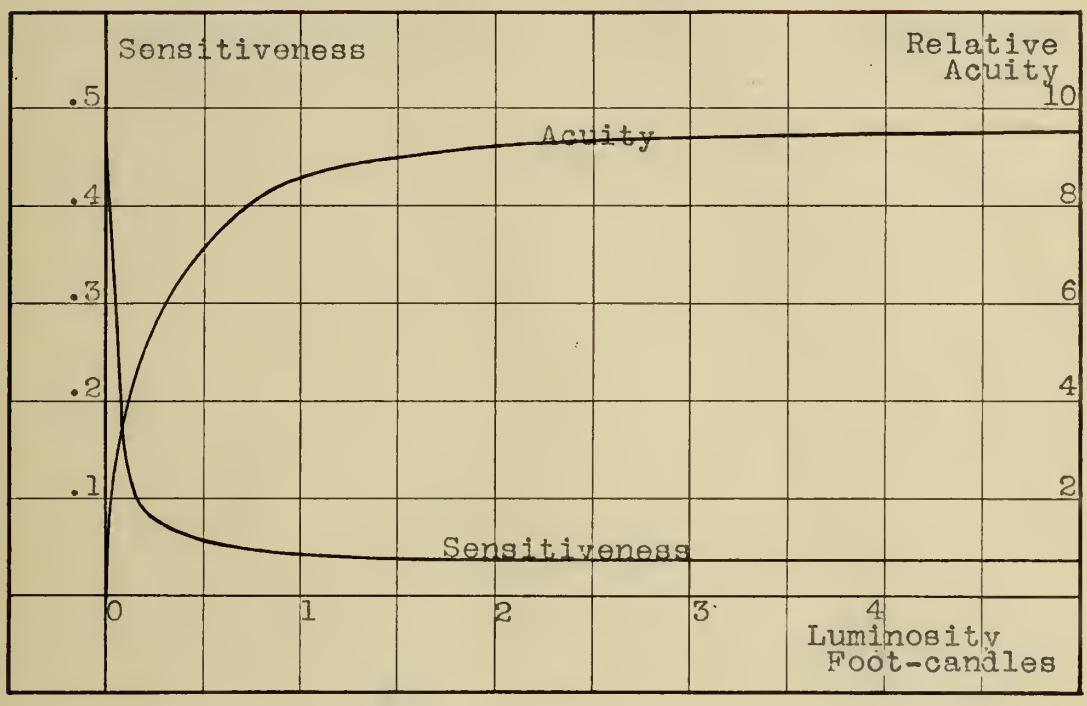


Figure 5

It was found in actual practice that the maximum intensity which could be used on the particular card employed ranged from about .01 to .0425 foot candles. By referring to the curves it is seen that at this intensity the sensitiveness of the eye is ten to twelve times that at normal intensity. The relative acuity is, however, correspondingly lower. This disadvantage would be overcome if a smaller type of sufficient clearness and distinctness could be used. This would require a higher intensity and thus increase the relative acuity. Under this condition the eye would be able to distinguish with more accuracy the variation in sharpness of detail, and the readings obtained under such condi-

tions would be much more reliable. Moreover the range of the instrument would be increased by the use of the smaller type.

A DISCUSSION OF THE STREET ILLUMINATION OF CHAMPAIGN AND A COMPARISON OF THIS ILLUMINATION WITH THE ILLUMINATION FROM A TUNGSTEN SYSTEM CONSUMING THE SAME POWER

The first system of artificial illumination used in Champaign was a system employing coal gas. It served as efficiently as was possible, until about 1890 when, due to the advance being made in artificial illumination it was replaced by an electric system. This system was called the old low tension arc system because of the low voltage across the arc. The lamps required 18 amperes direct current at a pressure of 35 volts.

The next step was to use a lower current lamp and was effected about three years later when 9.6 ampere direct current lamps operating under a pressure of 45 volts were installed. This system was in operation for approximately nine years and was then replaced by the present alternating current system using 6.6 ampere series lamp working under a pressure of 72 volts across the arc. There are about 150 lamps in the system distributed over three separate circuits each about equally loaded. The lamps are of the enclosed arc type with clear inner globe and outer globe and are not fitted with reflectors.

One fault of the system exists in the method of suspension due to its irregularity. The lamps are hung at distances from the street level varying from ten feet to twenty feet. The mean or average height was found to be about fourteen and one-half

feet. This irregularity interferes seriously with the efficiency of distribution. By referring to the characteristic curves for an arc lamp of the type used in the Champaign system, it is seen that the candle power in a vertical plane about the arc varies, the maximum occurring at approximately 80° with the vertical. Then if the lamp is suspended so low that this maximum is interfered with before it reaches a horizontal distance as great as it would with proper suspension, it is easily seen that much of the effective illumination is lost.

Another source of ineffectiveness is due to the fact that the town is growing away from the lamp system. In the west, southwest, and south portions this is becoming a proposition deserving serious consideration, since the illumination of these districts is almost zero. Even in the better lighted districts the lamps are distributed at such distances that the illumination is quite unsatisfactory. There is, except in a very few cases, a general scheme of distribution by which a lamp is placed at one end of a block, the distance to the next lamp being two blocks, which leaves a crossing between without a lamp. This gives a very low intensity at the middle crossing.

Still another, though probably not so serious a fault, is the fact that deep heavy shadows are cast by the lamps. This, together with the glare, produces a blinding effect which seemingly has the effect of reducing the illumination. This glare could be partially avoided by proper suspension.

The power consumed by the system is given as 80 kilo-

watts. With 150 lamps in the system this gives something over 500 watts per lamp. Since a 6.6 ampere lamp of this same type is rated to consume 425 watts, it will be seen that this is another source of inefficiency. Although seemingly not very important, when applied over a great length of time it becomes quite important in the cost of light.

The three factors entering into the cost of light are: the cost of plant equipment and plant operating expenses, the cost of electrical energy and the maintenance cost of the light system. It is evident that these three items will be present in any electrical installation the purpose of which is the transformation of heat energy into electrical energy and thence into light. In view of this fact it may be well to discuss each of them briefly and show by what each is affected.

Taking them up in the order named the first to be considered will be the cost of plant equipment and plant operating expenses, or as it is sometimes called, the cost of electrical service. It is made up of the cost of fuel, the cost of apparatus necessary to transform the latent energy of the fuel into electrical energy, and the wages paid the employees required to operate the plant. It is seen at once that this cost is practically constant for any given installation, for although there may be, and in the case of a lighting system will be, times when the load is very light, yet practically the entire force of employees must be kept instantly available in order to satisfy any demand which may be made upon the plant. Furthermore, the decrease in the cost of fuel during intervals of light load is inappreciable

since the generators and transforming devices must be operated continuously so that instantaneous service may be obtained by any customer.

The second item in the cost of light is the cost of electrical energy. It consists solely of the cost of electrical power required to give the desired amount of light under the given conditions, and should be considered separately from the fixed charges and the cost of the lamps. The usual method of measuring this cost is to find the product of the average rate of power consumption and time in hours. This product is the total energy consumed and is expressed as kilowatt hours;multiplied by the rate per kilowatt hour it gives the second item in the cost of light, namely, the cost of electrical energy. It matters not whether five kilowatt hours be considered as five kilowatts used for one hour, or one kilowatt used for a period of five hours; the cost will be the same in either case. Since this is true, it will be seen that the cost of electrical energy depends upon the amount of energy used.

The third item in the cost of light, the cost of lamp renewals, is in general, in a system using only incandescent lamps, the least significant of the three items which must be considered. It frequently happens, however, that for a system consisting of arc lamps of certain kinds, such as flame arcs, that the maintenance cost of the lamps far exceeds the cost of power, provided sufficiently low rates on the power used may be obtained. In the case of arc lamps the maintenance or renewal cost includes the cost of electrodes, globes, trimming and inspection, together with the

various repairs necessary from time to time. In an incandescent system the renewal cost consists of the cost of new lamps, made necessary by the burning out of the old, and the cost of cleaning.

On the whole, an incandescent system consuming the same power as a given arc system can be operated at a lower cost than the arc system, and by a proper distribution of units gives a better and more uniform illumination. As a means of showing this and also as a means of suggesting a possible substitute for the present system of arc illumination in Champaign, a comparison of two installations, one similar to the best section of the present system, and the other a tungsten system consuming the same amount of power will be made. Since the intensity along the street is the important object, the comparison will be based on the relative illuminations given by the two methods.

Some authorities advocate the use of horizontal illumination, or the illumination on a horizontal surface as a basis of comparison. Others advocate normal intensity, or the intensity

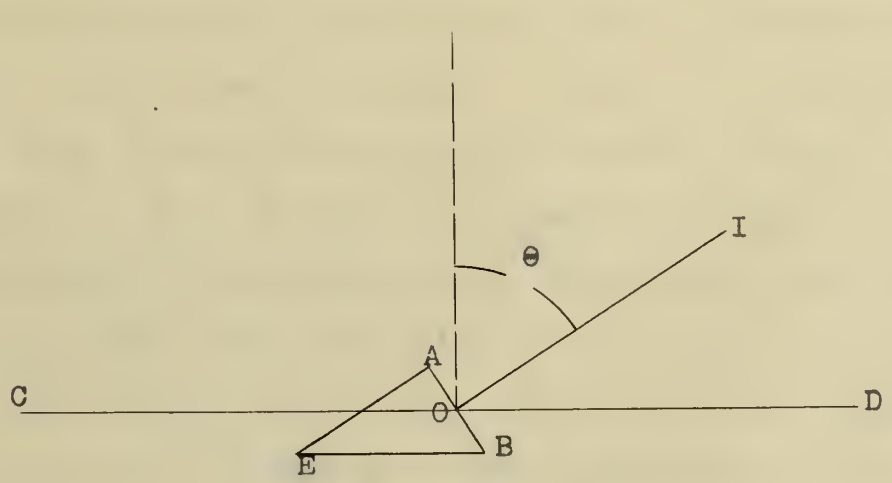
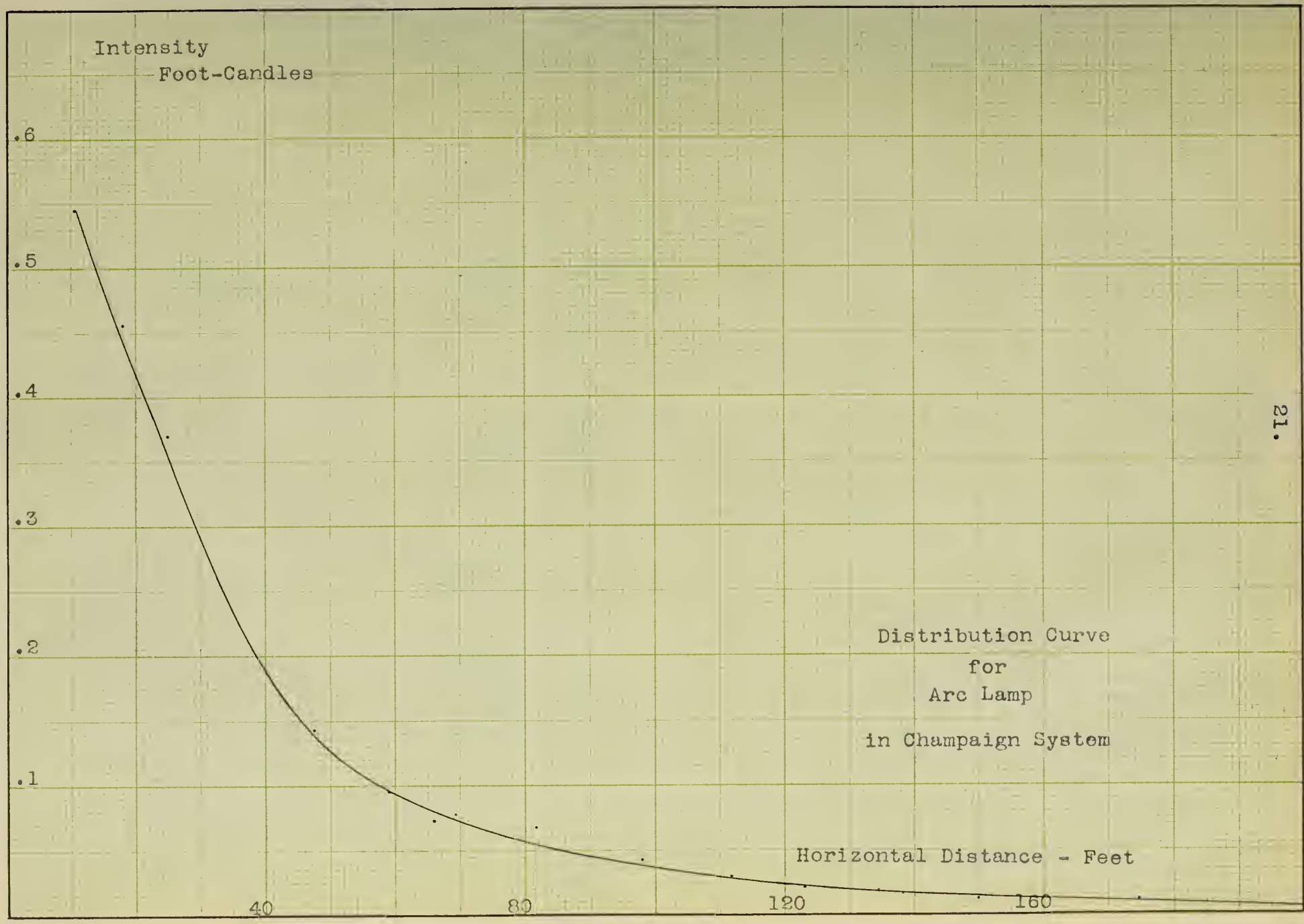


Figure 6.

on a plane normal to the beam of light. It will be seen that the normal intensity is greater than the horizontal intensity from the same source for from the diagram shown in Figure 6, the horizontal intensity on plane COD is equal to the normal intensity I on plane AOB multiplied by cos θ, where θ is the angle between the direction of the ray of light and the normal to the plane COD. The reason for using the factor cos θ may be found from considering triangle ABE. The normal intensity on plane AB is known and the horizontal intensity on EB, for instance, is desired. Now if EB is just two times as long as AB, it is easily seen that the intensity on EB will be one-half the intensity on AB, or the ratio of the intensities is 1:2 or AB to EB. The intensity on EB then in general will be $I \times \frac{AB}{EB}$. From the figure $\frac{AB}{EB}$ is cos θ, whence the horizontal intensity becomes I cos θ. Evidently, it is more convenient to use the normal intensity and the latter will therefore be used in this discussion.

The preliminary steps necessary for the comparison of the illumination from the two systems, were to procure distribution curves for the lamps to be used. Data on the arc lamps in the system under discussion are shown in Tables 1 and 2. The resulting curve is shown on Page 21. Sometimes it is also desirable to know something of the candle-power distribution about the lamp in a vertical plane. The most satisfactory method for determining this characteristic curve was found to be by calculating it from the horizontal distribution curve. The data as obtained for the characteristic curve is shown in Table Number 3.


Intensity
Foot-Candles
.6
.5
.4
.3
.2
.1
40
80
120
160
Distribution Curve
for
Arc Lamp
in Champaign System
Horizontal Distance - Feet

By referring to the characteristic curve as calculated it is seen that the values of candle-power as calculated directly from data as shown in Table Number 1, do not agree completely with those values on the curve. This is accounted for by the fact that the characteristic curve is derived from mean values as given by the distribution curve, while the values calculated from and shown in Table 1, are from values of intensities which are not necessarily on the distribution curve. Then since candle-

Table 1.

Results as obtained by Jasper:

Line of Type	Horizontal Distance.	Foot Candles. Normal	C. P.	Angles
7	98.5'	.0425	421	81° 38'
6	123.0'	.0215	329	83° 17'
5	134.4'	.0183	332	83° 50'
4	174.6'	.0121	363	85° 11'
3	185.0'	.0077	264	85° 30'

Results as obtained by Heater:

7	95.7'	.0421	392	81° 30'
6	116.8'	.0299	412	82° 55'
5	132.5'	.0252	445	83° 45'
4	137.2'	.0164	310	83° 58'
3	150.4'	.0116	251	84° 28'

Table 2

Results obtained with Sharp-Miller Instrument

Horiz. Distance feet	Normal Intensities Foot-Candles		
	By E.F.H.	By E.M.J.	Mean
10.5	.545	.545	.545
18.0	.460	.455	.458
25.0	.370	.370	.370
25.2	.372	.379	.376
47.5	.145	.142	.143
66.0	.076	.0765	.076
81.5	.068	.068	.068
98.0	.043	.043	.043

Table 3

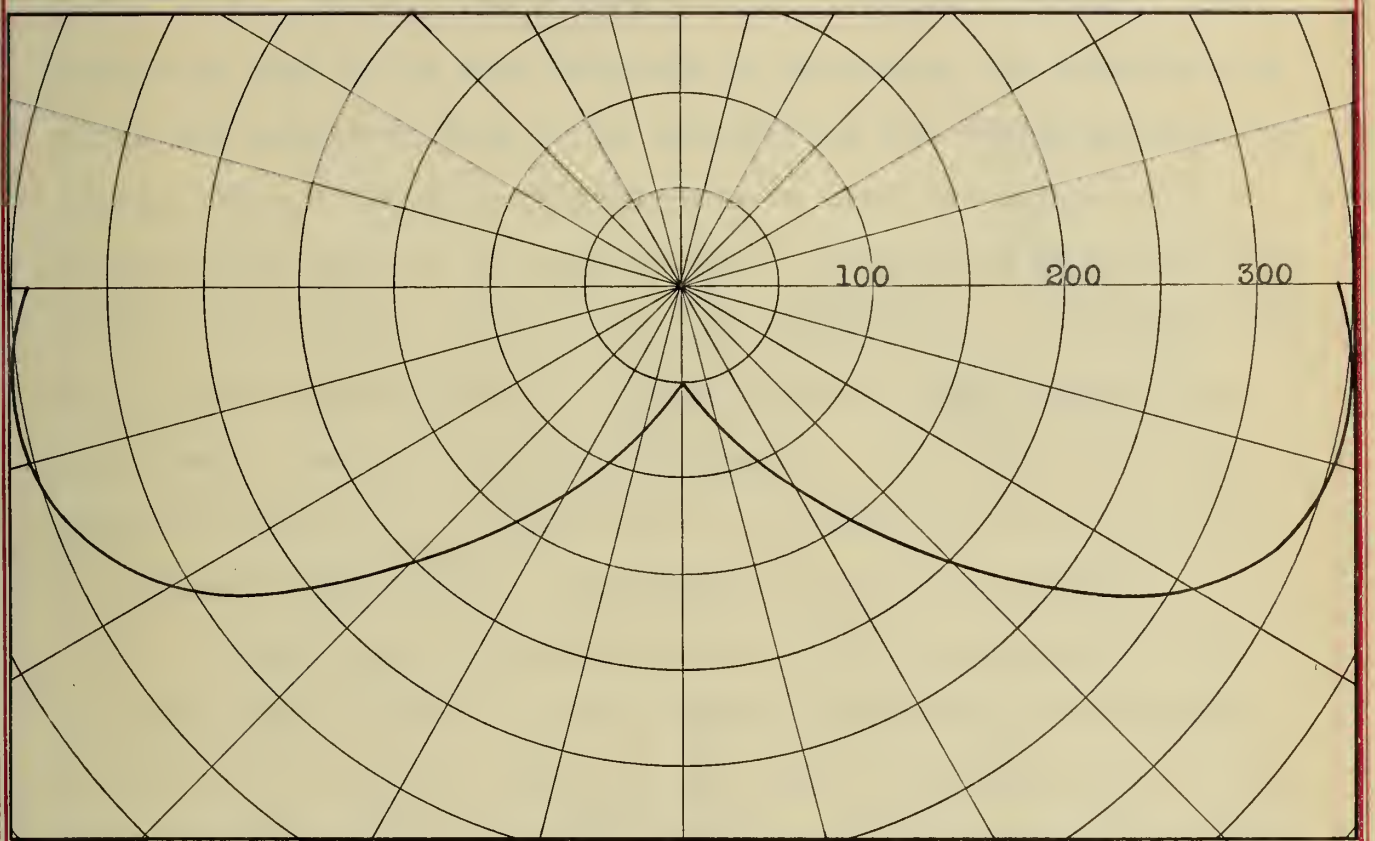
CHARACTERISTIC CURVE CALCULATED FROM THE

HORIZONTAL DISTRIBUTION CURVE

Horiz. Distance feet	Intensity Foot-Candles Normal	Candle Power	Angle with Vertical
18	.545	176.5	38°25'
20.5	.500	210	45°00'
23	.460	242	51°05'
27	.400	291	57°10'
29	.370	311	59°50'
33	.300	326	63°50'
36.5	.250	332	66°40'
41.4	.200	342	70°15'
48.5	.150	352	72°40'
59.5	.100	354	76°00'
84.4	.050	356	80°00'
113.	.030	384	82°40'
127	.025	397	83°25'
165	.015	407	85°00'

Based on 14.5 feet height.

6.6 AMPERE A. C. ARC LAMP



Clear outer and inner globes.

Based on calculations from the distribution curve from the system using 14.5 feet as the average height of suspension.

power equals intensity times distance squared, at low intensities a small numerical difference or error in the value of intensity means a large per cent error in its value and a similiarly large per cent error in the value for candle power. This indicates that it is more accurate to determine the distribution curve and take data from it in calculating the characteristic for candle power. The data in Table 2 were used for points on the distribution curve at distances closer to the lamp than could be obtained with the luminometer as constructed. The luminometer was used for some points out of the range of the Sharpe-Miller instrument, the two serving as a check on each other for the intermediate points. By reference to the curve shown on page 21 it is found that the two instruments agree quite closely.

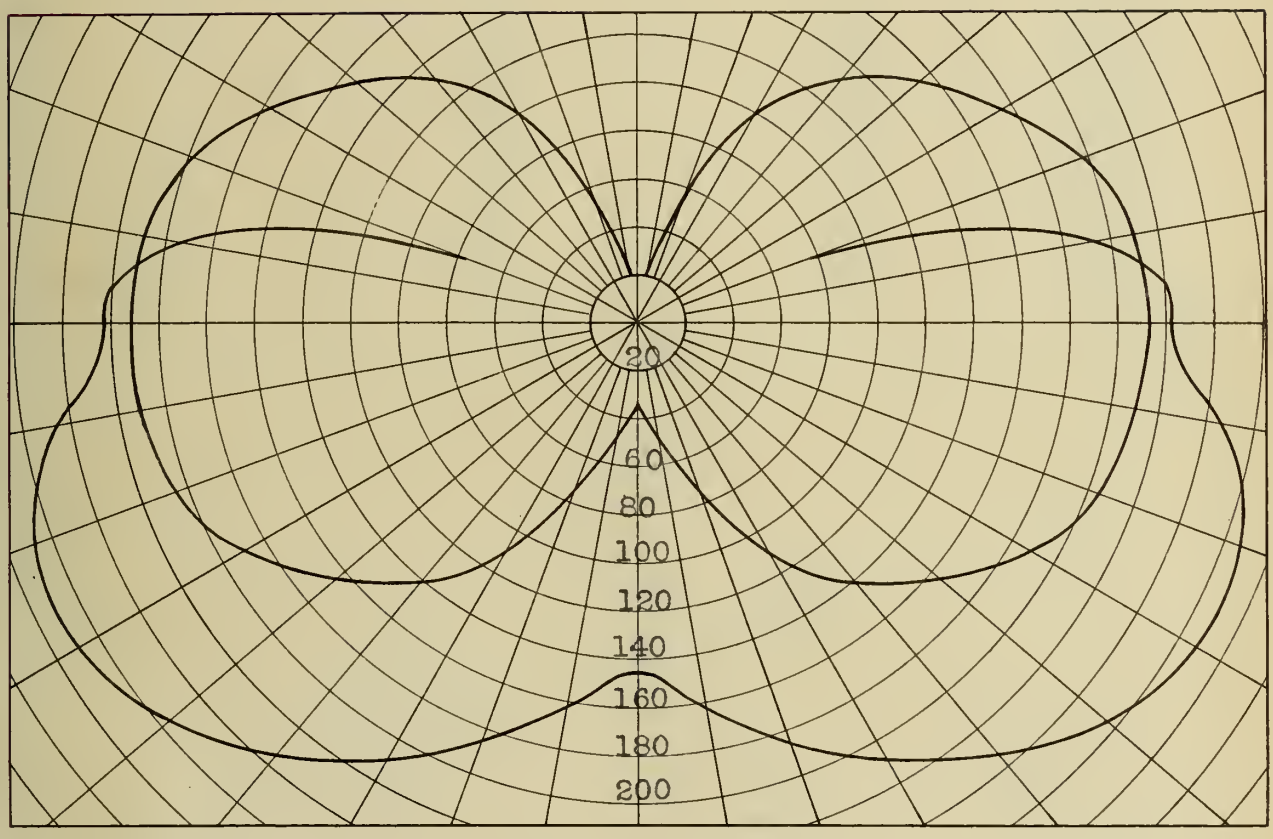
The type of lamp to be used in the comparison is the 250 watt mazda series lamp with clear globe and with a particular style of reflector known as the radial wave reflector. The characteristic curve for this type of lamp and reflector is shown on the following page.

The data in Table 5 taken directly from the distribution curve, show the intensity of illumination at various horizontal distances from the arc lamp as obtained from the present system. These data were obtained from observations made on the entire system and will be applied to the three blocks of Hill Street included between Neil Street and Prairie Street. This particular area was selected because of the fact that within

250 WATT MAZDA SERIES LAMP

with

24-INCH RADIAL WAVE REFLECTOR



Clear globe lamp.

Paint enamel reflecting surface.

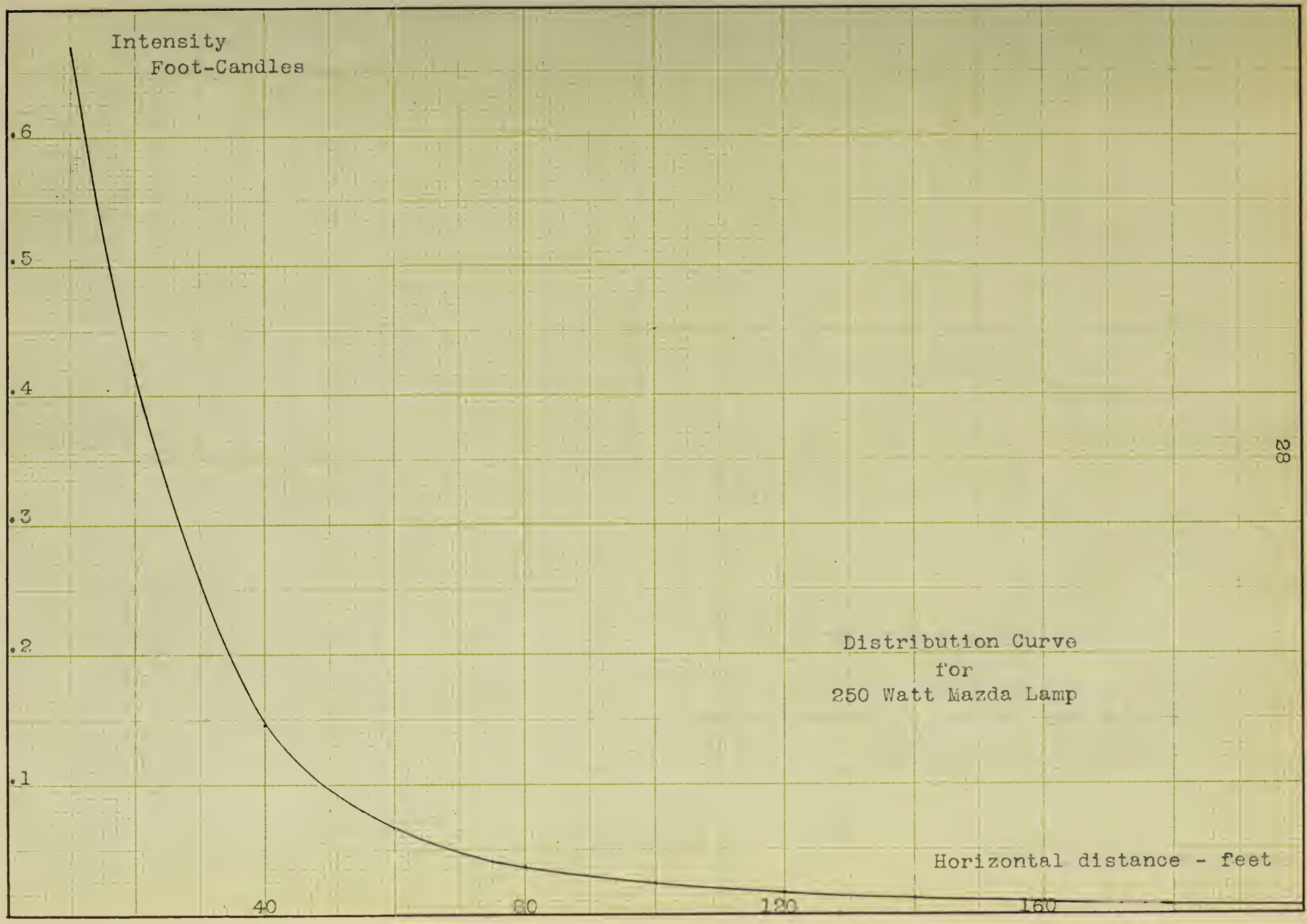
Lamp operated at top voltage giving 212 horizontal candle-power. Consuming 1.18 watts per candle-power.

Table 4

DISTRIBUTION CURVE FOR THE MAZDA LAMP

Horiz. Distance feet	Intensity Foot-Candles	Candle Power	Angle with Vertical
5	.728	182	18°28'
10	.670	218	33°40'
20	.417	261	53°8'
30	.258	289	63°27'
40	.146	267	69°27'
60	.0664	260	75°58'
80	.037	248	79°22'
100	.024	244	81°28'
120	.0163	238	82°52'
140	.012	231	83°53'
180	.007	228	85°14'
220	.0046	225	86°6'
260	.0033	223	86°42'

Curve on the following page.


Intensity
Foot-Candles
.6
.5
.4
.3
.2
.1
40
80
120
160
Distribution Curve
for
250 Watt Mazda Lamp
Horizontal distance - feet

these three blocks there are four arc lamps, which is the maximum number found in any equivalent distance throughout the entire residence district of Champaign making it the best lighted section.

Table 5

Horiz. Distance feet	Intensity Foot-Candles
25	.370
50	.132
75	.061
100	.037
150	.017
200	.010

It is intended to discuss a tungsten system that consumes the same power as the arc system. As stated previously the watts consumed by each arc lamp are approximately 530 watts. For the four lamps spoken of above, the watts would be 2120. This would operate eight 250 watt mazda lamps with 120 watts extra. This would mean that the number of mazda lamps which could be substituted would be double the present number of arcs. This number could be distributed to the best advantage over the entire city by placing one lamp at a corner for every block. This method is using only one-half the number that could be used for laying out the three block comparison system. But since there are approximately 300 blocks which require good illumination, 300 lamps or the number using about the same power as the 150 arc lamps will be distributed one for each block.

The next item to be considered is the distribution of luminous intensity along the street. In the district under discussion the distance between lamps is one block or about 435 feet. From the horizontal distribution curve the intensity from

one arc lamp at the middle of the distance between lamps is considerably less than .01 foot-candles. Due to both lamps the intensity becomes approximately .01 foot-candles. This, however, is based on data taken when the lamps were at their maximum brilliancy. Therefore, this intensity would not be effective at all times.

By placing the mazda lamps at the corners at a height of 15 feet the intensity from one lamp at the middle point of the block is found to be about .0048 foot-candles. For the resultant intensity from the two lamps the value .0096 foot-candles is reached. This shows a tendency to be lower than the resultant intensity from the arcs and is for that reason misleading. It must be remembered, however, that the intensity from a tungsten lamp is infinitely more constant than is the intensity from an arc lamp. For this reason the resultant illumination from the two tungstens would be very appreciably greater when the mean over a reasonable length of time was considered.

Now, proceeding to the remainder of the arc system it is found that the arcs are as a rule two blocks apart. This gives a resultant illumination, as previously stated, that is practically zero at the intervening street corner. This is, of course, very undesirable as by the effect of contrast and shadows mentioned earlier, the effectiveness suffers. In the tungsten system as laid out thus far, the lowest intensity will be somewhat less than .01 foot-candles; but this is better than the lowest intensity in the best lighted district in the arc

system as operating at present. This value, although low, is much better than the zero value and since there are more units the contrast between the darker and lighter places will not be so noticeable. The fact that the shadows cast by the tungsten lamp are not so sharp as those cast by the arc lamp, also aids this effect. Furthermore, the quality of the light from the tungsten lamp has a much more agreeable physiological effect on the eye. The fifteen foot suspension will place the lamps in a position such that the direct beams will enter the eye at a much more favorable angle than is the case with many of the arc lamps. The comparison of the cost of the light produced by these two systems will show much in favor of the tungsten system. The annual fixed charge is the first item in this cost and consists of interest and depreciation determined by the purchase and installation costs of the permanent system with some reference to the period of its useful life. The relation of the annual fixed charge per lamp for the two types of lamps under consideration is shown in Table 6. The advantage is in favor of the tungsten lamp.

The second item which has been termed maintenance cost represents the cost of renewals of lamps or parts, inspection and repairs. The relation of this cost in the two cases is shown in the same table with the advantage slightly in favor of the arc lamp.

The third item is simply the cost of the electrical energy consumed and depends entirely upon the rate charged by

Table 6

COMPARISON OF ANNUAL OPERATING COSTS

OF 6.6 AMPERE A. C. ARC LAMP

and

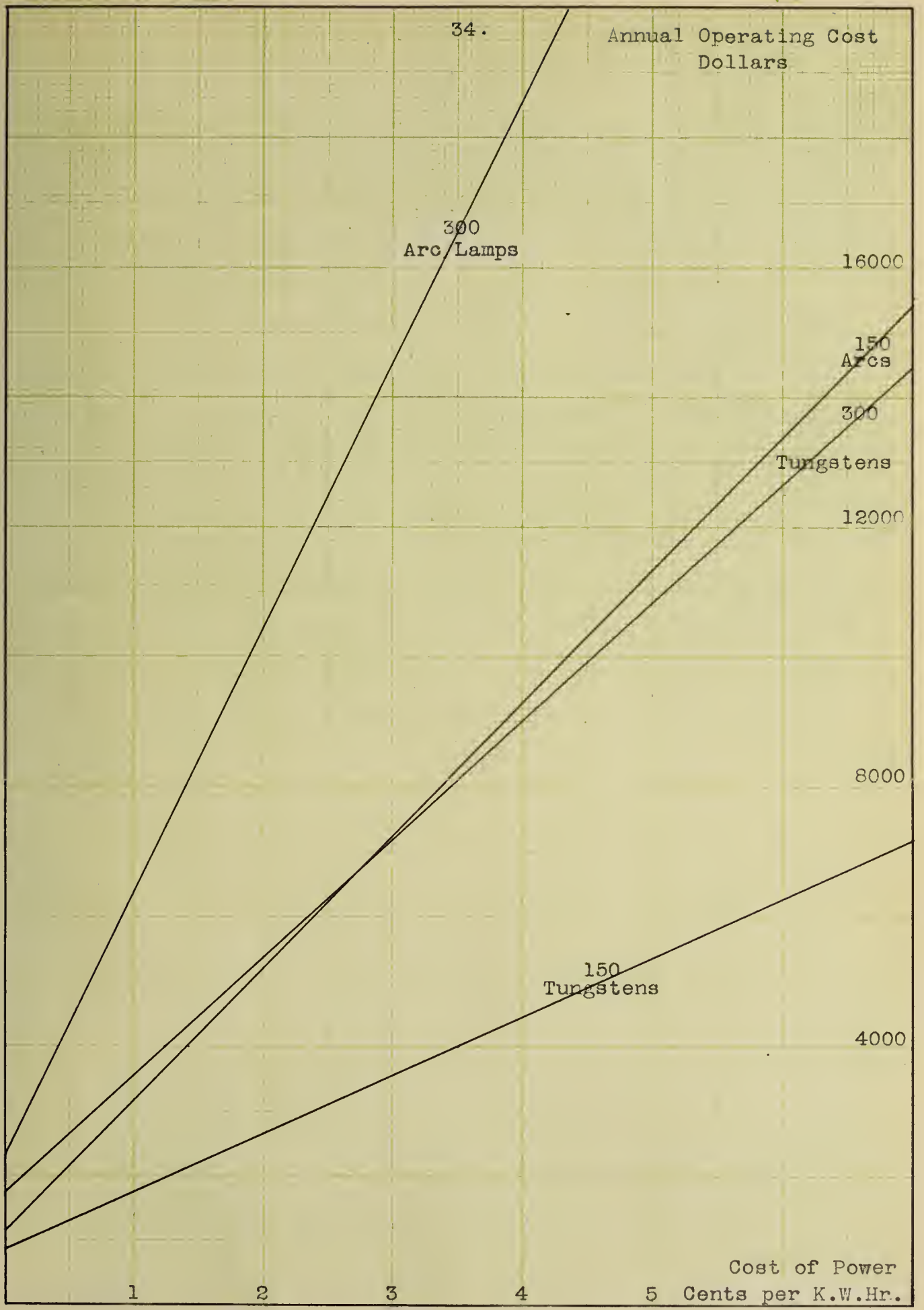
250 WATT MAZDA LAMP

	ARC	MAZDA	ARC	MAZDA
Energy Cost	1 cent / K.W.Hr.		2 cents / K.W.Hr.	
Annual Fixed Charge	3.20	1.19	3.20	1.19
Maintenance	4.67	4.75	4.67	4.75
Energy	13.35	5.90	26.70	11.80
Total Annual Operating cost	21.22	11.84	34.57	17.74
Annual Cost for 150 Lamps	3180.00	1775.00	5170.00	2660.00
Annual Cost for 300 Lamps	6360.00	3550.00	10340.00	5320.00
Energy Cost	3 cents / K.W.Hr.		4 cents / K.W.Hr.	
Annual Fixed Charge	3.20	1.19	3.20	1.19
Maintenance	4.67	4.75	4.67	4.65
Energy	40.05	17.70	53.40	23.60
Total Annual Operating Cost	47.92	23.64	61.27	29.54
Annual Cost for 150 Lamps	7190.00	3546.00	9240.00	4425.00
Annual Cost for 300 Lamps	14380.00	7092.00	18480.00	8850.00
Energy Cost	5 cents / K.W.Hr.		6 cent / K.W.Hr.	
Annual Fixed Charge	3.20	1.19	3.20	1.19
Maintenance	4.67	4.75	4.67	4.75
Energy	66.75	29.50	80.10	35.40
Total Annual Operating Cost	74.62	35.44	87.97	41.34
Annual Cost for 150 Lamps	11193.00	5316.00	13195.50	6201.00
Annual Cost for 300 Lamps	22368.00	10632.00	26391.00	12402.00

Based on 2500 hour schedule.

the plant supplying it and upon the length of time the lamps are burned. In this system the "moonlight schedule" is followed giving about 2500 hours per year that the lamps are in service. For single lamps the advantage under this head is also in favor of the tungsten lamp. At this point much depends on the cost of power. For instance, at three cents per kilowatt hour as shown in the first part of the table, 150 arc lamps and 300 mazda lamps have practically equal total annual operating costs. But at one cent per kilowatt hour the total annual cost for 150 arc lamps is almost $400.00 less than the total annual costs for 300 tungsten lamps. This seeming discrepancy is accounted for by the fact that the energy item in the operating costs of the arc lamp is the ruling item and also that the maintenance costs are slightly lower than those for the tungsten lamps. The curves on the following page show the relation of annual operating charges and energy cost for 150 arc lamps and tungsten lamps as well as for 300 arc lamps and 300 tungsten lamps.

Highly efficient lamps, as the tungsten lamp, which have comparatively high maintenance costs, give the lowest operating cost when power rates are high. On the other hand, an inefficient lamp with low maintenance cost operates at a much lower cost when the power rate is low than does the efficient lamp. Nevertheless, in the case under consideration the gain in the quality of the illumination is so very marked that, even if the power costs were such as to give the high operating costs for the tungsten system, the ultimate gain would be strongly in


Annual Operating Cost
Dollars
300
Arc Lamps
16000
150
Arcs
300
Tungstens
12000
8000
150
Tungstens
4000
1
2
3
4
5
Cost of Power
Cents per K.W.Hr.

favor of the tungsten system. Moreover, many points in the city now without lamps would be effectively covered by the tungsten system with an illumination equal to that in the best light districts under the arc system.

A change from the arc system to the tungsten system would involve the construction of new circuits similar to the ones now in use as well as the installation of transformers for these circuits. The reflectors also would need to be considered as they are omitted in the table of costs. Their cost would not be very heavy, however. These costs would, it is true, increase the first cost of changing systems, but this disadvantage would be more than offset by the advantages gained in superior illumination. On the whole, the present arc system could be advantageously replaced by a tungsten system such as the one described above.

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